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Precision measurement of the mass and lifetime of the Ξ_b^0 baryon

The LHCb collaboration[†]

Abstract

Using a proton-proton collision data sample corresponding to an integrated luminosity of 3 fb^{-1} collected by LHCb at center-of-mass energies of 7 and 8 TeV, about 3800 $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$, $\Xi_c^+ \rightarrow p K^- \pi^+$ signal decays are reconstructed. From this sample, the first measurement of the Ξ_b^0 baryon lifetime is made, relative to that of the Λ_b^0 baryon. The mass differences $M(\Xi_b^0) - M(\Lambda_b^0)$ and $M(\Xi_c^+) - M(\Lambda_c^+)$ are also measured with precision more than four times better than the current world averages. The resulting values are

$$\begin{aligned} \frac{\tau_{\Xi_b^0}}{\tau_{\Lambda_b^0}} &= 1.006 \pm 0.018 \pm 0.010, \\ M(\Xi_b^0) - M(\Lambda_b^0) &= 172.44 \pm 0.39 \pm 0.17 \text{ MeV}/c^2, \\ M(\Xi_c^+) - M(\Lambda_c^+) &= 181.51 \pm 0.14 \pm 0.10 \text{ MeV}/c^2, \end{aligned}$$

where the first uncertainty is statistical and the second is systematic. The relative rate of Ξ_b^0 to Λ_b^0 baryon production is measured to be

$$\frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}} \cdot \frac{\mathcal{B}(\Xi_b^0 \rightarrow \Xi_c^+ \pi^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-)} \cdot \frac{\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)} = (1.88 \pm 0.04 \pm 0.03) \times 10^{-2},$$

where the first factor is the ratio of fragmentation fractions, $b \rightarrow \Xi_b^0$ relative to $b \rightarrow \Lambda_b^0$. Relative production rates as functions of transverse momentum and pseudorapidity are also presented.

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Over the last two decades great progress has been made in understanding the nature of hadrons containing beauty quarks. A number of theoretical tools have been developed to describe their decays. One of them, the heavy quark expansion (HQE) [1–8], expresses the decay widths as an expansion in powers of Λ_{QCD}/m_b , where Λ_{QCD} is the energy scale at which the strong coupling constant becomes large, and m_b is the b -quark mass. At leading order in the HQE, all weakly decaying b hadrons (excluding those containing charm quarks) have the same lifetime, and differences enter only at order $(\Lambda_{\text{QCD}}/m_b)^2$. In the baryon sector, one expects for the lifetimes $\tau(\Xi_b^0) \approx \tau(\Lambda_b^0)$ [8] and $\tau(\Xi_b^0)/\tau(\Xi_b^-) = 0.95 \pm 0.06$ [9, 10]. Precise measurements of the Ξ_b^0 and Ξ_b^- lifetimes would put bounds on the magnitude of the higher order terms in the HQE. A number of approaches exist to predict the b -baryon masses [11–19]. As predictions for the masses span a large range, more precise mass measurements will help to refine these models.

Hadron collider experiments have collected large samples of b -baryon decays, which have enabled increasingly precise measurements of their masses and lifetimes [20–25]. These advances include 1% precision on the lifetime of the Λ_b^0 baryon [20] and 0.3 MeV/ c^2 uncertainty on its mass [22]. Progress has also been made on improving the precision on the masses of the Σ_b^\pm [26], Ξ_b^0 [27–29], Ξ_b^- [26, 30] and Ω_b^- [26, 30] baryons. The strange-beauty baryon measurements are still limited by small sample sizes owing to their low production rates, and either low detection efficiency or small branching fractions.

In this Letter, we present the first measurement of the Ξ_b^0 lifetime and report the most precise measurement of its mass, using a sample of about 3800 $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$, $\Xi_c^+ \rightarrow pK^- \pi^+$ signal decays. Unless otherwise noted, charge conjugate processes are implied throughout. The $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$, $\Lambda_c^+ \rightarrow pK^- \pi^+$ decay is used for normalization, as it has the same final state, and is kinematically very similar. The ratio of Ξ_b^0 to Λ_b^0 baryon production rates, and its dependence on pseudorapidity, η , and transverse momentum, p_T , are also presented. We also use the $\Xi_c^+ \rightarrow pK^- \pi^+$ and $\Lambda_c^+ \rightarrow pK^- \pi^+$ signals to make the most precise measurement of the Ξ_c^+ mass to date. In what follows, we use X_b (X_c) to refer to either a Ξ_b^0 (Ξ_c^+) or Λ_b^0 (Λ_c^+) baryon.

The measurements use proton-proton (pp) collision data samples collected by the LHCb experiment corresponding to an integrated luminosity of 3 fb $^{-1}$, of which 1 fb $^{-1}$ was recorded at a center-of-mass energy of 7 TeV and 2 fb $^{-1}$ at 8 TeV. The LHCb detector [31] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$, designed for the study of particles containing b or c quarks. The detector includes a high-precision tracking system that provides a momentum measurement with precision of about 0.5% from 2–100 GeV/ c and impact parameter (IP) resolution of 20 μm for particles with large p_T . Ring-imaging Cherenkov detectors [32] are used to distinguish charged hadrons. Photon, electron and hadron candidates are identified using a calorimeter system, followed by a set of detectors to identify muons [33].

The trigger [34] consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction [34, 35]. About 57% of the recorded X_b events are triggered at the hardware level by one or more of the final state particles in the signal X_b decay. The remaining 43% are triggered only on other activity in the event. We refer to these two classes of events

as triggered on signal (TOS) and triggered independently of signal (TIS). The software trigger requires a two-, three- or four-track secondary vertex with a large sum of the transverse momentum of the particles and a significant displacement from the primary pp interaction vertices (PVs). At least one particle should have $p_T > 1.7 \text{ GeV}/c$ and χ_{IP}^2 with respect to any primary interaction greater than 16, where χ_{IP}^2 is defined as the difference in χ^2 of a given PV fitted with and without the considered particle included. The signal candidates are required to pass a multivariate software trigger selection algorithm [35].

Proton-proton collisions are simulated using PYTHIA [36] with a specific LHCb configuration [37]. Decays of hadronic particles are described by EVTGEN [38], in which final state radiation is generated using PHOTOS [39]. The interaction of the generated particles with the detector and its response are implemented using the GEANT4 toolkit [40] as described in Ref. [41].

Candidate X_b decays are reconstructed by combining in a kinematic fit selected $X_c \rightarrow pK^-\pi^+$ candidates with a π^- candidate (referred to as the bachelor). Each X_b candidate is associated to the PV with the smallest χ_{IP}^2 . The X_c daughters are required to have $p_T > 100 \text{ MeV}/c$, and the bachelor pion is required to have $p_T > 500 \text{ MeV}/c$. To improve the signal purity, all four final state particles are required to be significantly displaced from the PV and pass particle identification (PID) requirements. The PID requirements on the X_c daughter particles have an efficiency of 74%, while reducing the combinatorial background by a factor of four. The PID requirements on the bachelor pion are 98% efficient, and remove about 60% of the cross-feed from $X_b \rightarrow X_c K^-$ decays. Cross-feed from misidentified $D_{(s)}^+ \rightarrow K^+ K^- \pi^+$, $D^{*+} \rightarrow D^0(K^+ K^-)\pi^+$, and $D^+ \rightarrow K^- \pi^+ \pi^+$ decays is removed by requiring either the mass under these alternate decay hypotheses to be inconsistent with the known $D_{(s)}^{(*)+}$ masses [42], or that the candidate satisfy more stringent PID requirements. The efficiency of these vetoes is about 98% and they reject 28% of the background. The X_c candidate is required to be within $20 \text{ MeV}/c^2$ of the nominal X_c mass [42].

To further improve the signal-to-background ratio, a boosted decision tree (BDT) [43, 44] algorithm using eight input variables is employed. Three variables from the X_b candidate are used, χ_{IP}^2 , the vertex fit χ_{vtx}^2 , and the χ_{VS}^2 , which is the increase in χ^2 of the PV fit when the X_b is forced to have zero lifetime relative to the nominal fit. For the X_c baryon, we use the χ_{IP}^2 , and amongst its daughters, we take the minimum p_T , the smallest χ_{IP}^2 , and the largest distance between any pair of daughter particles. Lastly, the χ_{IP}^2 of the bachelor π^- is used. The BDT is trained using simulated signal decays to represent the signal and candidates from the high X_b mass region (beyond the fit region) to describe the background distributions. A selection is applied that provides 97% signal efficiency while rejecting about 50% of the combinatorial background with respect to all previously applied selections.

For each X_b candidate, the mass is recomputed using vertex constraints to improve the momentum resolution; X_c mass constraints are not used since the Ξ_c^+ mass is not known to sufficient precision. The resulting X_b mass spectra are simultaneously fitted to the sum of a signal component and three background contributions. The X_b signal shape is parameterized as the sum of two Crystal Ball (CB) functions [45], with a common mean.

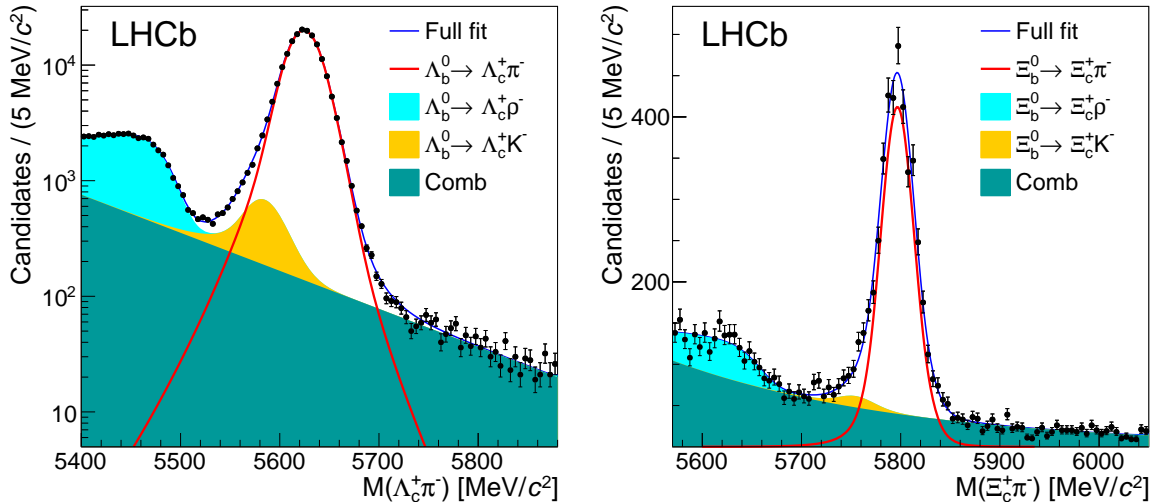


Figure 1: Invariant mass spectrum for (left) $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ and (right) $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$ candidates along with the projections of the fit.

The shape parameters are freely varied in the fit to data. The Λ_b^0 and Ξ_b^0 signal shape parameters are common except for their means and widths. The Ξ_b^0 widths are fixed to be 0.6% larger than those for the Λ_b^0 , based on simulation.

The main background sources are misidentified $X_b \rightarrow X_c K^-$ decays, partially reconstructed $X_b \rightarrow X_c \rho^-$ and $\Lambda_b^0 \rightarrow \Sigma_c^+ \pi^-$ decays, and combinatorial background. The $X_b \rightarrow X_c K^-$ background shape is obtained from simulated decays that are weighted according to PID misidentification rates obtained from $D^{*+} \rightarrow D^0(K^- \pi^+) \pi^+$ calibration data. The $X_b \rightarrow X_c K^-$ yield is fixed to be 3.1% of the $X_b \rightarrow X_c \pi^-$ signal yield, which is the product of the misidentification rate of 42% and the ratio of branching fractions, $\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ K^-)/\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) = 0.0731 \pm 0.0023$ [27]. The assumed equality of this ratio for Ξ_b^0 and Λ_b^0 is considered as a source of systematic uncertainty. The partially reconstructed backgrounds are modeled empirically using an ARGUS [46] function, convolved with a Gaussian shape; all of its shape parameters are freely varied in the fit. The combinatorial background shape is described using an exponential function with a freely varied shape parameter.

The results of the simultaneous binned extended maximum likelihood fits are shown in Fig. 1. Peaking backgrounds from charmless final states are investigated using the X_c sidebands and are found to be negligible. We observe $(180.5 \pm 0.5) \times 10^3$ $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ and 3775 ± 71 $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$ signal decays. The mass difference is determined to be

$$\Delta M_{X_b} \equiv M(\Xi_b^0) - M(\Lambda_b^0) = 172.44 \pm 0.39 (\text{stat}) \text{ MeV}/c^2.$$

The data are also used to make the first determination of the relative lifetime $\tau(\Xi_b^0)/\tau(\Lambda_b^0)$. This is performed by fitting the efficiency-corrected ratio of yields, $N_{\text{cor}}(\Xi_b^0)/N_{\text{cor}}(\Lambda_b^0)$, as a function of decay time to an exponential function, $e^{\beta t}$. The

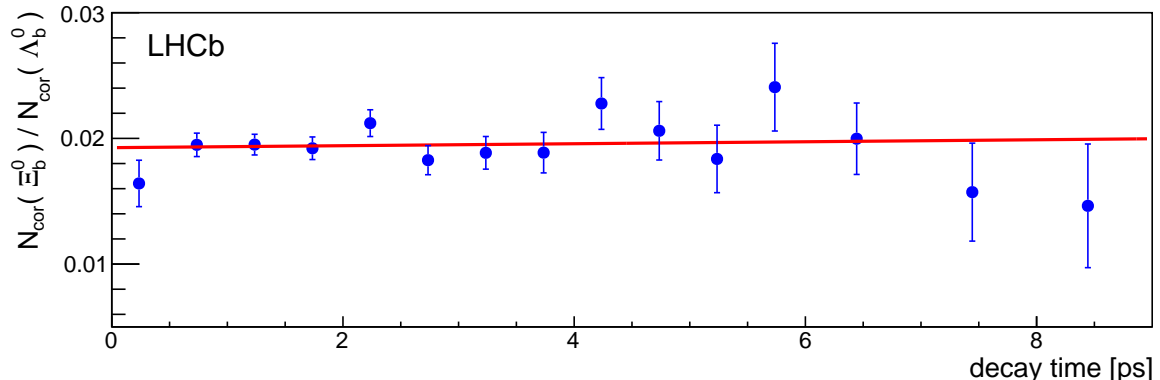


Figure 2: Efficiency-corrected yield ratio of $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$ relative to $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ decays in bins of decay time. A fit using an exponential function is shown. The uncertainties are statistical only.

fitted value of β thus determines $1/\tau_{\Lambda_b^0} - 1/\tau_{\Xi_b^0}$. Since the Λ_b^0 lifetime is known to high precision, $\tau(\Xi_b^0)$ is readily obtained. The data are binned in 0.5 ps bins from 0 – 6 ps, and 1 ps bins from 7 to 9 ps. The same fit as described above for the full sample is used to fit the mass spectra in each time bin. The signal and partially-reconstructed background shapes are fixed to the values from the fit to the full data sample, since they do not change with decay time, but the combinatorial background shape is freely varied in each time bin fit.

The measured yield ratio in each time bin is corrected by the relative efficiency, $\epsilon(\Lambda_b^0)/\epsilon(\Xi_b^0)$, as obtained from simulated decays. This ratio is consistent with a constant value of about 0.93, except for the 0.0 – 0.5 ps bin, which has a value of about 0.7. This lower value is expected due to the differing lifetimes, $\tau(\Xi_c^+) \approx 0.45$ ps \gg $\tau(\Lambda_c^+) \approx 0.2$ ps, and the χ_{IP}^2 requirements in the trigger and offline selections. The 7% overall lower efficiency for the Λ_b^0 mode is due to the larger momenta of the daughters in the Ξ_b^0 decay.

The efficiency-corrected yield ratio is shown in Fig. 2, along with the fit to an exponential function. The points are placed at the weighted average time value within each bin, assuming an exponential distribution with lifetime equal to $\tau(\Lambda_b^0)$. The bias due to this assumption is negligible. From the fit, we find $\beta = (0.40 \pm 1.21) \times 10^{-2}$ ps $^{-1}$. Using the measured Λ_b^0 lifetime from LHCb of $1.468 \pm 0.009 \pm 0.008$ ps [20], we obtain

$$\frac{\tau_{\Xi_b^0}}{\tau_{\Lambda_b^0}} = \frac{1}{1 - \beta\tau_{\Lambda_b^0}} = 1.006 \pm 0.018 \text{ (stat)},$$

consistent with equal lifetimes of the Ξ_b^0 and Λ_b^0 baryons.

We have also investigated the relative production rates of Ξ_b^0 and Λ_b^0 baryons as functions of p_T and η . The p_T bin boundaries are 0, 4, 6, 8, 10, 12, 16, 20, up to a maximum of 30 GeV/c, and the η bins are each 0.5 units wide ranging from 2 to 5. The efficiency-corrected yield ratios are shown in Fig. 3. A smooth change in the relative production rates, at about the 10-20% level, is observed. Since the p_T dependence of Ξ_b^0

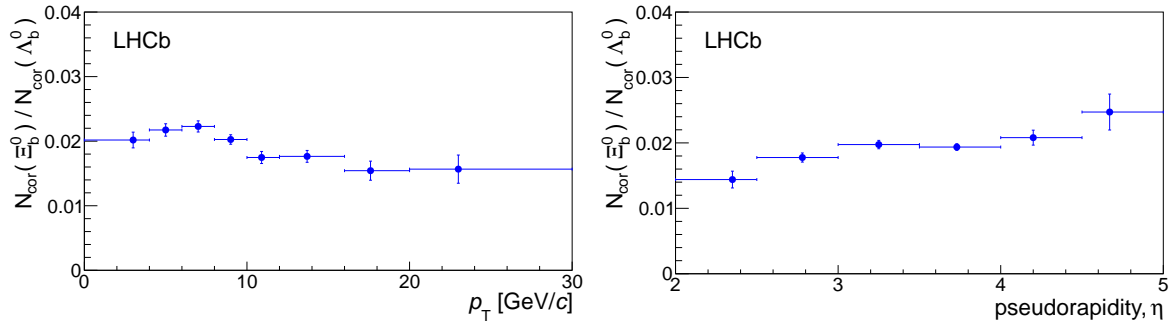


Figure 3: Efficiency-corrected yield ratio of $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$ relative to $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ decays as functions of (left) p_T and (right) pseudorapidity, η . The points are positioned along the horizontal axis at the weighted average value within each bin. The uncertainties are statistical only.

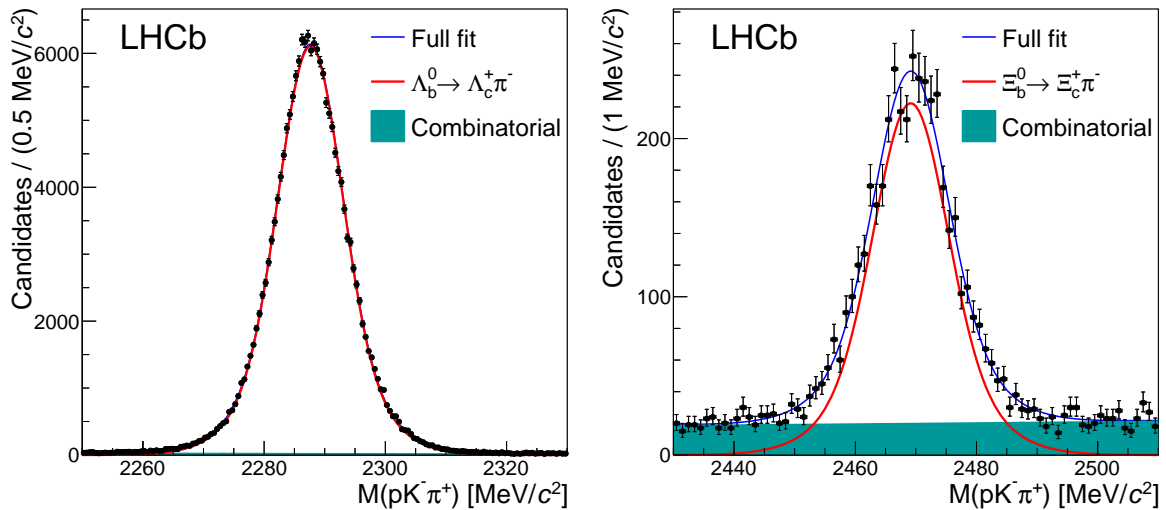


Figure 4: Distributions of the $pK^-\pi^+$ invariant mass for (left) Λ_c^+ and (right) Ξ_c^+ candidates along with the projections of the fit.

and Λ_b^0 production are similar, this implies that the steep p_T dependence of Λ_b^0 baryon to B^0 meson production measured in Ref. [47] also occurs for Ξ_b^0 baryons.

The large sample of $\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$ decays is exploited to measure the Ξ_c^+ mass. Signal X_b candidates within $50 \text{ MeV}/c^2$ of their respective peak values are selected, and a simultaneous fit to the Λ_c^+ and Ξ_c^+ mass spectra is performed. For this measurement, we remove the $20 \text{ MeV}/c^2$ restriction on the X_c mass. The sum of two CB functions is used to describe the signal and an exponential shape describes the background. The signal shape parameters are common, except for their means and widths. The larger Ξ_c^+ resolution is due to the greater energy release in the decay. The mass distributions and the results of the fit are shown in Fig. 4. The fitted mass difference is

$$\Delta M_{X_c} \equiv M(\Xi_c^+) - M(\Lambda_c^+) = 181.51 \pm 0.14 \text{ (stat) MeV}/c^2.$$

The results presented are all ratio or difference measurements, reducing their sensitivity to most potential biases. A summary of the systematic uncertainties is given in Table 1. Unless otherwise noted, systematic uncertainties are assigned by taking the difference between the nominal result and the result after a particular variation. In all measurements, possible dependencies on the signal and background models are investigated by exploring alternative shapes and fit ranges (for mass differences). Uncertainties are combined by summing all sources of uncertainty in quadrature.

For the mass difference measurements, common and separate variations in the fraction of $X_b \rightarrow X_c K^-$ by $\pm 1\%$ (absolute) are used to assign the cross-feed uncertainty. Shifts in the momentum scale of $\pm 0.03\%$ [48] are applied coherently to both signal and normalization mode to determine the momentum scale uncertainty. Validation of the procedure on simulated decays shows no biases on the results. The uncertainty due to the limited size of those simulated samples are taken as a systematic error.

For the relative lifetime measurement, the relative acceptance uncertainty is dominated by a potential bias in the first time bin. The uncertainty is assessed by dropping this bin from the fit. Potential bias due to the BDT's usage of χ_{IP}^2 information is examined by correcting the data using simulated efficiencies with a tighter BDT requirement. The smaller lifetime of the Λ_b^0 baryon assumed in the simulation (1.426 ps) has a negligible impact on the measured lifetime ratio. Lastly, the finite size of the simulated samples is also taken into account.

For the relative production rate, the signal and background shape uncertainties, and the $X_b \rightarrow X_c K^-$ cross-feed uncertainties are treated in the same way as above. For the relative acceptance we include contributions from (i) the geometric acceptance by comparing PYTHIA 6 and PYTHIA 8; (ii) the X_c Dalitz structure, by reweighting the efficiencies according to the distributions seen in data, and (iii) the lower efficiency in the 0 – 0.5 ps bin by requiring $\tau(X_b) > 0.5$ ps. The uncertainty in the relative trigger efficiency is estimated by taking the difference in the average trigger efficiency, when using the different TOS/TIS fractions in data and simulation. A correction and an uncertainty due to the 20 MeV/ c^2 mass range on X_c is obtained using the results of the X_c mass fits. The results for the 7 TeV and 8 TeV data differ by about 1% and are statistically compatible with each other. In summary, a 3 fb $^{-1}$ pp collision data set is used to make the first measurement of the Ξ_b^0 lifetime. The relative and absolute lifetimes are

$$\begin{aligned} \frac{\tau_{\Xi_b^0}}{\tau_{\Lambda_b^0}} &= 1.006 \pm 0.018 \text{ (stat)} \pm 0.010 \text{ (syst)}, \\ \tau_{\Xi_b^0} &= 1.477 \pm 0.026 \text{ (stat)} \pm 0.014 \text{ (syst)} \pm 0.013 (\Lambda_b^0) \text{ ps}, \end{aligned}$$

where the last uncertainty in $\tau_{\Xi_b^0}$ is due to the precision of $\tau_{\Lambda_b^0}$ [20]. This establishes that the Ξ_b^0 and Λ_b^0 lifetimes are equal to within 2%. We also make the most precise measurements of the mass difference and Ξ_b^0 mass as

$$\begin{aligned} M(\Xi_b^0) - M(\Lambda_b^0) &= 172.44 \pm 0.39 \text{ (stat)} \pm 0.17 \text{ (syst) MeV}/c^2, \\ M(\Xi_b^0) &= 5791.80 \pm 0.39 \text{ (stat)} \pm 0.17 \text{ (syst)} \pm 0.26 (\Lambda_b^0) \text{ MeV}/c^2, \end{aligned}$$

Table 1: Summary of systematic uncertainties on the reported measurements. Below, PR represents the relative uncertainty on the production ratio measurement.

Source	ΔM_{X_b} (MeV/ c^2)	ΔM_{X_c} (MeV/ c^2)	$\tau(\Xi_b^0)/\tau(\Lambda_b^0)$ (%)	PR (%)
Signal & back. model	0.06	0.05	0.1	0.5
$X_c K^-$ reflection	0.02	—	—	0.3
Momentum scale	0.06	0.06	—	-
Sim. sample size	0.14	0.07	0.9	0.6
Detection efficiency	—	—	0.4	1.0
BDT requirement	—	—	0.2	—
Trigger	—	—	—	1.3
X_c mass range	—	—	—	0.3
Total	0.17	0.10	1.0	1.9

where we have used $M(\Lambda_b^0) = 5619.36 \pm 0.26$ MeV/ c^2 [22]. The mass and mass difference are consistent with, and about five times more precise than the value recently obtained in Ref. [27].

We also measure the mass difference $M(\Xi_c^+) - M(\Lambda_c^+)$, and the corresponding Ξ_c^+ mass, yielding

$$M(\Xi_c^+) - M(\Lambda_c^+) = 181.51 \pm 0.14 \text{ (stat)} \pm 0.10 \text{ (syst)} \text{ MeV}/c^2,$$

$$M(\Xi_c^+) = 2467.97 \pm 0.14 \text{ (stat)} \pm 0.10 \text{ (syst)} \pm 0.14 (\Lambda_c^+) \text{ MeV}/c^2,$$

where $M(\Lambda_c^+) = 2286.46 \pm 0.14$ MeV/ c^2 [42] is used. These values are consistent with and at least three times more precise than other measurements [29, 42].

Furthermore, the relative yield of Ξ_b^0 and Λ_b^0 baryons as functions of p_T and η are measured, and found to smoothly vary by about 20%. The relative production rate inside the LHCb acceptance is measured to be

$$\frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}} \cdot \frac{\mathcal{B}(\Xi_b^0 \rightarrow \Xi_c^+ \pi^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-)} \cdot \frac{\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)}{\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)} = (1.88 \pm 0.04 \pm 0.03) \times 10^{-2}.$$

The first fraction is the ratio of fragmentation fractions, $b \rightarrow \Xi_b^0$ relative to $b \rightarrow \Lambda_b^0$, and the remainder are branching fractions. Assuming naive Cabibbo factors [49], namely $\mathcal{B}(\Xi_b^0 \rightarrow \Xi_c^+ \pi^-)/\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) \approx 1$ and $\mathcal{B}(\Xi_c^+ \rightarrow p K^- \pi^+)/\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+) \approx 0.1$, one obtains $\frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}} \approx 0.2$. The results presented in this paper provide stringent tests of models that predict the properties of beauty hadrons.

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References

- [1] V. A. Khoze and M. A. Shifman, *Heavy quarks*, Sov. Phys. Usp. **26** (1983) 387.
- [2] I. I. Bigi and N. Uraltsev, *Gluonic enhancements in non-spectator beauty decays: An inclusive mirage though an exclusive possibility*, Phys. Lett. **B280** (1992) 271.
- [3] I. I. Y. Bigi, N. G. Uraltsev, and A. I. Vainshtein, *Nonperturbative corrections to inclusive beauty and charm decays: QCD versus phenomenological models*, Phys. Lett. **B293** (1992) 430, [arXiv:hep-ph/9207214](#).
- [4] B. Blok and M. A. Shifman, *The rule of discarding $1/N_c$ in inclusive weak decays. 1.*, Nucl. Phys. **B399** (1993) 441, [arXiv:hep-ph/9207236](#).
- [5] B. Blok and M. A. Shifman, *The rule of discarding $1/N_c$ in inclusive weak decays. 2.*, Nucl. Phys. **B399** (1993) 459, [arXiv:hep-ph/9209289](#).
- [6] M. Neubert, *B decays and the heavy quark expansion*, Adv. Ser. Direct. High Energy Phys. **15** (1998) 239, [arXiv:hep-ph/9702375](#).
- [7] N. Uraltsev, *Heavy quark expansion in beauty and its decays*, [arXiv:hep-ph/9804275](#).
- [8] I. I. Y. Bigi, *The QCD perspective on lifetimes of heavy flavor hadrons*, [arXiv:hep-ph/9508408](#).
- [9] A. J. Lenz, *Mixing and lifetimes of b -hadrons*, AIP Conf. Proc. **1026** (2008) 36, [arXiv:0802.0977](#).

- [10] A. J. Lenz, *Lifetimes and HQE*, arXiv:1405.3601, invited contribution to the Kolya Uraltsev Memorial Book.
- [11] D. Ebert, R. N. Faustov, and V. O. Galkin, *Masses of heavy baryons in the relativistic quark model*, Phys. Rev. **D72** (2005) 034026, arXiv:hep-ph/0504112.
- [12] N. Mathur, R. Lewis, and R. M. Woloshyn, *Charmed and bottom baryons from lattice NRQCD*, Phys. Rev. **D66** (2002) 014502, arXiv:hep-ph/0203253.
- [13] X. Liu *et al.*, *Bottom baryons*, Phys. Rev. **D77** (2008) 014031, arXiv:0710.0123.
- [14] E. E. Jenkins, *Model-independent bottom baryon mass predictions in the $1/N_c$ expansion*, Phys. Rev. **D77** (2008) 034012, arXiv:0712.0406.
- [15] R. Roncaglia, D. B. Lichtenberg, and E. Predazzi, *Predicting the masses of baryons containing one or two heavy quarks*, Phys. Rev. **D52** (1995) 1722, arXiv:hep-ph/9502251.
- [16] M. Karliner, B. Keren-Zur, H. J. Lipkin, and J. L. Rosner, *The quark model and b baryons*, Annals Phys. **324** (2009) 2, arXiv:0804.1575.
- [17] M. Karliner, *Heavy quark spectroscopy and prediction of bottom baryon masses*, Nucl. Phys. Proc. Suppl. **187** (2009) 21, arXiv:0806.4951.
- [18] Z. Ghalei and A. Akbar Rajabi, *Single charm and beauty baryon masses in the hypercentral approach*, Eur. Phys. J. Plus **127** (2012) 141.
- [19] J.-R. Zhang and M.-Q. Huang, *Heavy baryon spectroscopy in QCD*, Phys. Rev. **D78** (2008) 094015, arXiv:0811.3266.
- [20] LHCb collaboration, R. Aaij *et al.*, *Precision measurement of the ratio of the Λ_b^0 to \bar{B}^0 lifetimes*, arXiv:1402.6242, to appear in Phys. Lett. B.
- [21] LHCb collaboration, R. Aaij *et al.*, *Measurements of the B^+ , B^0 , B_s^0 meson and Λ_b^0 baryon lifetimes*, JHEP **04** (2014) 114, arXiv:1402.2554.
- [22] LHCb collaboration, R. Aaij *et al.*, *Study of beauty hadron decays into pairs of charm hadrons*, Phys. Rev. Lett. **112** (2014) 202001, arXiv:1403.3606.
- [23] LHCb collaboration, R. Aaij *et al.*, *Measurement of the Ξ_b^- and Ω_b^- baryon lifetimes*, arXiv:1405.1543, submitted to PLB.
- [24] ATLAS collaboration, G. Aad *et al.*, *Measurement of the Λ_b lifetime and mass in the ATLAS experiment*, Phys. Rev. **D87** (2013) 032002, arXiv:1207.2284.
- [25] CMS collaboration, S. Chatrchyan *et al.*, *Measurement of the Λ_b^0 lifetime in pp collisions at $\sqrt{s} = 7$ TeV*, JHEP **07** (2013) 163, arXiv:1304.7495.

- [26] CDF collaboration, T. Aaltonen *et al.*, *Measurement of the masses and widths of the bottom baryons Σ_b^\pm and $\Sigma_b^{*\pm}$* , Phys. Rev. **D85** (2012) 092011, [arXiv:1112.2808](#).
- [27] LHCb collaboration, R. Aaij *et al.*, *Study of beauty baryon decays to $D^0 p h^-$ and $\Lambda_c^+ h^-$ final states*, Phys. Rev. **D89** (2014) 032001, [arXiv:1311.4823](#).
- [28] CDF collaboration, T. Aaltonen *et al.*, *Observation of the Ξ_b^0 baryon*, Phys. Rev. Lett. **107** (2011) 102001, [arXiv:1107.4015](#).
- [29] CDF collaboration, T. A. Aaltonen *et al.*, *Mass and lifetime measurements of bottom and charm baryons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, Phys. Rev. **D89** (2014) 072014, [arXiv:1403.8126](#).
- [30] LHCb collaboration, R. Aaij *et al.*, *Measurements of the Λ_b^0 , Ξ_b^- and Ω_b^- baryon masses*, Phys. Rev. Lett. **110** (2013) 182001, [arXiv:1302.1072](#).
- [31] LHCb collaboration, A. A. Alves Jr. *et al.*, *The LHCb detector at the LHC*, JINST **3** (2008) S08005.
- [32] M. Adinolfi *et al.*, *Performance of the LHCb RICH detector at the LHC*, Eur. Phys. J. **C73** (2013) 2431, [arXiv:1211.6759](#).
- [33] A. A. Alves Jr. *et al.*, *Performance of the LHCb muon system*, JINST **8** (2013) P02022, [arXiv:1211.1346](#).
- [34] R. Aaij *et al.*, *The LHCb trigger and its performance in 2011*, JINST **8** (2013) P04022, [arXiv:1211.3055](#).
- [35] V. V. Gligorov and M. Williams, *Efficient, reliable and fast high-level triggering using a bonsai boosted decision tree*, JINST **8** (2013) P02013, [arXiv:1210.6861](#).
- [36] T. Sjöstrand, S. Mrenna, and P. Skands, *PYTHIA 6.4 physics and manual*, JHEP **05** (2006) 026, [arXiv:hep-ph/0603175](#); T. Sjöstrand, S. Mrenna, and P. Skands, *A brief introduction to PYTHIA 8.1*, Comput. Phys. Commun. **178** (2008) 852, [arXiv:0710.3820](#).
- [37] I. Belyaev *et al.*, *Handling of the generation of primary events in GAUSS, the LHCb simulation framework*, Nuclear Science Symposium Conference Record (NSS/MIC) **IEEE** (2010) 1155.
- [38] D. J. Lange, *The EvtGen particle decay simulation package*, Nucl. Instrum. Meth. **A462** (2001) 152.
- [39] P. Golonka and Z. Was, *PHOTOS Monte Carlo: a precision tool for QED corrections in Z and W decays*, Eur. Phys. J. **C45** (2006) 97, [arXiv:hep-ph/0506026](#).

- [40] Geant4 collaboration, J. Allison *et al.*, *Geant4 developments and applications*, IEEE Trans. Nucl. Sci. **53** (2006) 270; Geant4 collaboration, S. Agostinelli *et al.*, *Geant4: a simulation toolkit*, Nucl. Instrum. Meth. **A506** (2003) 250.
- [41] M. Clemencic *et al.*, *The LHCb simulation application, GAUSS: design, evolution and experience*, J. Phys. Conf. Ser. **331** (2011) 032023.
- [42] Particle Data Group, J. Beringer *et al.*, *Review of particle physics*, Phys. Rev. **D86** (2012) 010001, and 2013 partial update for the 2014 edition.
- [43] L. Breiman, J. H. Friedman, R. A. Olshen, and C. J. Stone, *Classification and regression trees*, Wadsworth international group, Belmont, California, USA, 1984.
- [44] R. E. Schapire and Y. Freund, *A decision-theoretic generalization of on-line learning and an application to boosting*, Jour. Comp. and Syst. Sc. **55** (1997) 119.
- [45] T. Skwarnicki, *A study of the radiative cascade transitions between the Upsilon-prime and Upsilon resonances*, PhD thesis, Institute of Nuclear Physics, Krakow, 1986, DESY-F31-86-02.
- [46] ARGUS collaboration, H. Albrecht *et al.*, *Measurement of the polarization in the decay $B \rightarrow J/\psi K^*$* , Phys. Lett. **B340** (1994) 217.
- [47] LHCb collaboration, R. Aaij *et al.*, *Study of the kinematic dependences of Λ_b^0 production in pp collisions and a measurement of the $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ branching fraction*, arXiv:1405.6842, submitted to JHEP.
- [48] LHCb collaboration, R. Aaij *et al.*, *Precision measurements of D meson mass differences*, JHEP **06** (2013) 065, arXiv:1304.6865.
- [49] N. Cabibbo, *Unitary symmetry and leptonic decays*, Phys. Rev. Lett. **10** (1963) 531.